# Flexible Design and Operation of a Smart Charging Microgrid

Annette G. Skowronska (TARDEC, OU)
Vijitashwa Pandey (OAKLAND UNIVERSITY)
Zissimos P. Mourelatos (OAKLAND UNIVERSITY)
David Gorsich, Matt Castanier (TARDEC)

SAE World Congress
April 8, 2014

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**08 APR 2014** | 2. REPORT TYPE<br>**Briefing Charts** | 3. DATES COVERED<br>**08-01-2014 to 09-03-2014** |

4. TITLE AND SUBTITLE
**Flexible Design and Operation of a Smart Charging Microgrid**

5a. CONTRACT NUMBER
**W56hzv-04-2-0001**

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
**Annette Skowronska; Vijitashwa Pandey; Zissimos Mourelatos; Matt Castanier; David Gorsich**

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**OAKLAND UNIVERSITY,2200 N. Squirrel Road,Rochester,Mi,48309**

8. PERFORMING ORGANIZATION REPORT NUMBER
**; #24610**

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
**U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000**

10. SPONSOR/MONITOR'S ACRONYM(S)
**TARDEC**

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
**#24610**

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**Briefing Charts for SAE World Congress 2014**

14. ABSTRACT
**A microgrid is a controllable group of interconnected loads and distributed energy sources, including renewables, for grid-connected or island mode operation**

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Public Release** | **26** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

# Introduction

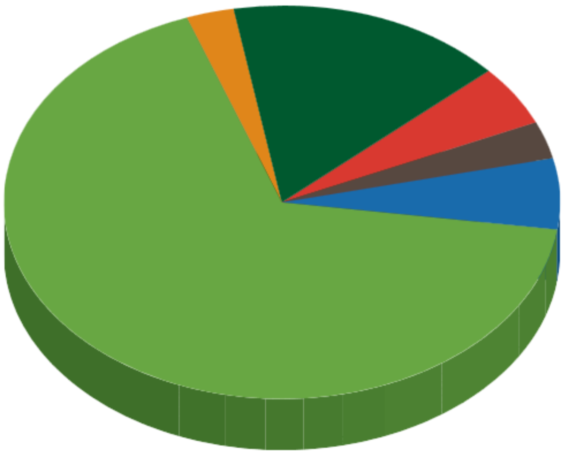
***A microgrid is a controllable group of interconnected loads and distributed energy sources, including renewables, for grid-connected or island mode operation***

Wheeler Army Airfield Installation in Hawaii

# Presentation Outline

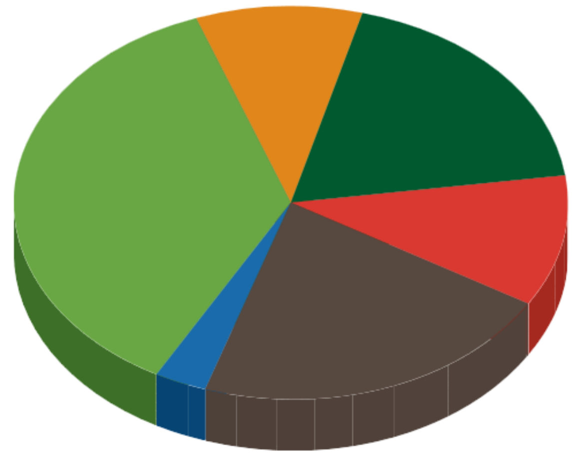
- Motivation
- Designing a Reliable Microgrid
- Repairable Systems
- Microgrid and V2G Overview
- Case Study
- Optimization Problem and Results
- Conclusions and Future Work

# Reliability and Cost Efficiency Contributors



**Peacetime**

- Combat Vehicles (3%)
- Combat Aircraft (16%)
- Tactical Vehicles (5%)
- Generators (3%)
- Non-Tactical Vehicles (6%)
- Facilities (67%)



**Contingency Operations**

- Combat Vehicles (10%)
- Combat Aircraft (19%)
- Tactical Vehicles (11%)
- Generators (22%)
- Non-Tactical Vehicles (3%)
- Facilities (37%)

"U.S. Army Energy Security and Sustainability: Vital to National Defense" April 2011

# Microgrid as a Flexible System

- A microgrid is a repairable system that needs to accommodate varying operating conditions.
  - A deterministic design tends to be not feasible
  - Robust design can still become suboptimal as operating conditions change
  - A flexible design accommodates changes in operating conditions and is preferred
- Design of a microgrid involves multiple conflicting objectives such as: reliability, cost and planning horizon.
- To calculate these long-term metrics the computational effort becomes excessive.
- This work aims at flexible design that simultaneously attacks the computational effort.

# Microgrid and V2G Design Problem

Determine optimal microgrid architecture (number, size, and type of energy sources including hybrid vehicles) and source dispatching

initial plus inventory

to minimize acquisition and operation cost

fuel, repairs for readiness (e.g.MFFP)

and maximize performance (reliable service of a time-dependent and uncertain load), considering maintainability, repair strategy, inventory, reset, and energy storage. Incorporate flexible approach to microgrid design that "learns" from its behavior (loads and sources) and responds accordingly.

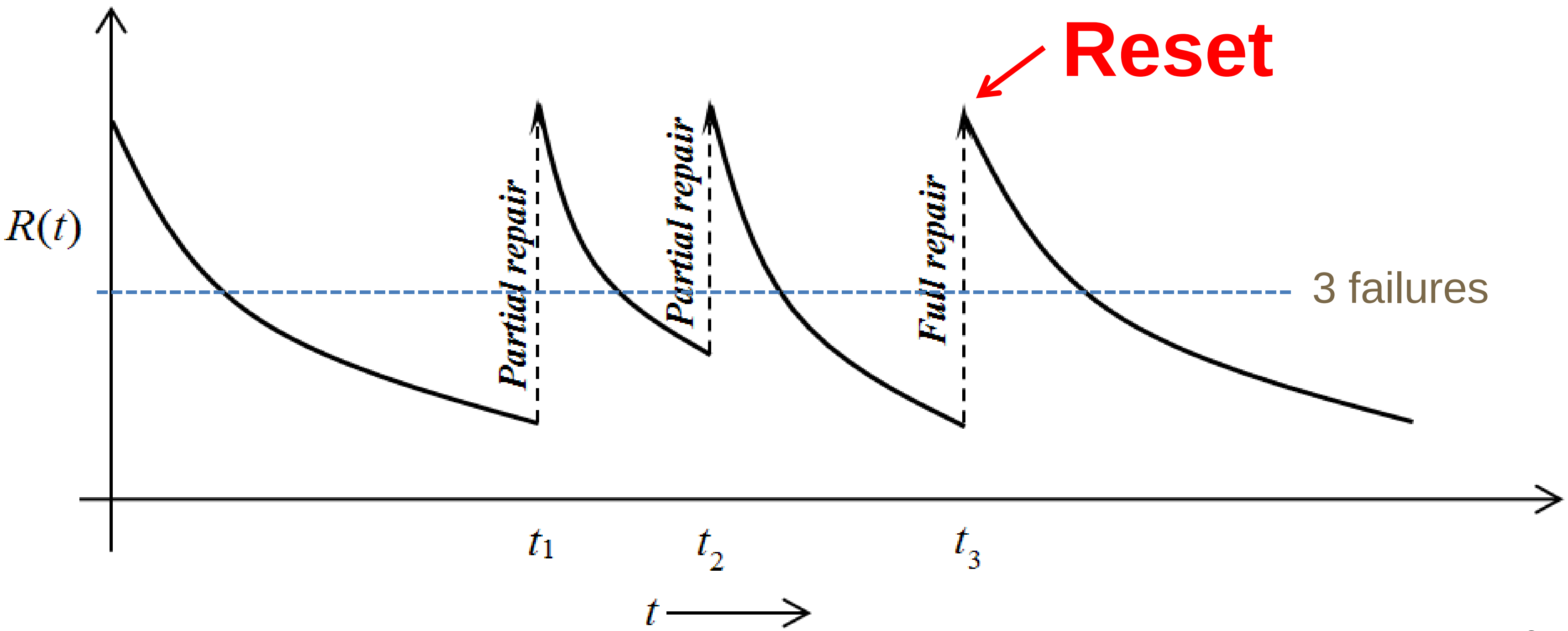
# What is a Reliable Microgrid?

- Failure is the inability of the microgrid to meet load requirements.
  - Load exceeds maximum capacity of energy sources with no component failures (load shedding is required).
  - Load exceeds available capacity of energy sources due to component failures.
- Failures are expected because of the stochasticity regardless of how well the loads are modeled.
- Microgrid is treated as a **repairable system**.

# Repairable and Non-repairable Systems

Reliability of a non-repairable system is the probability that a system has not failed at any time before the time of interest.

What is the reliability of a repairable system?

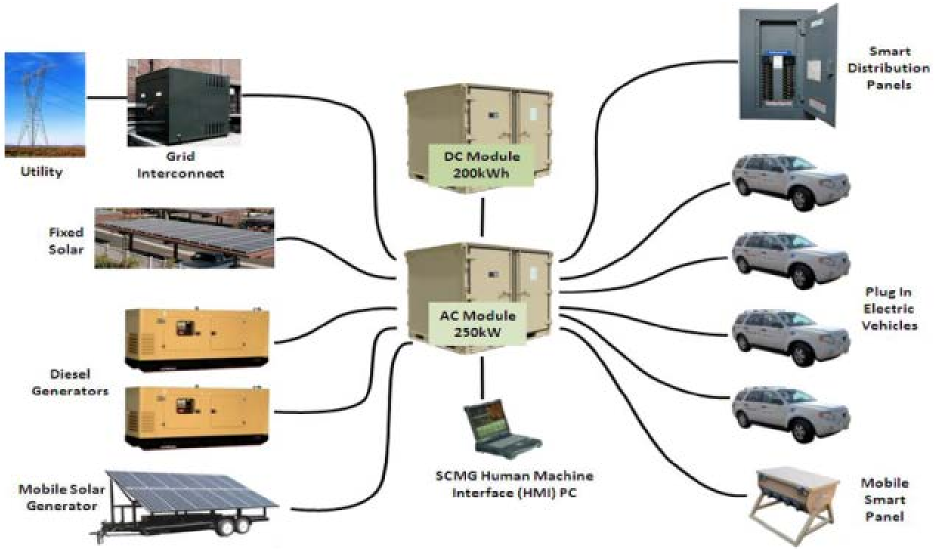


# Metrics for Repairable Systems

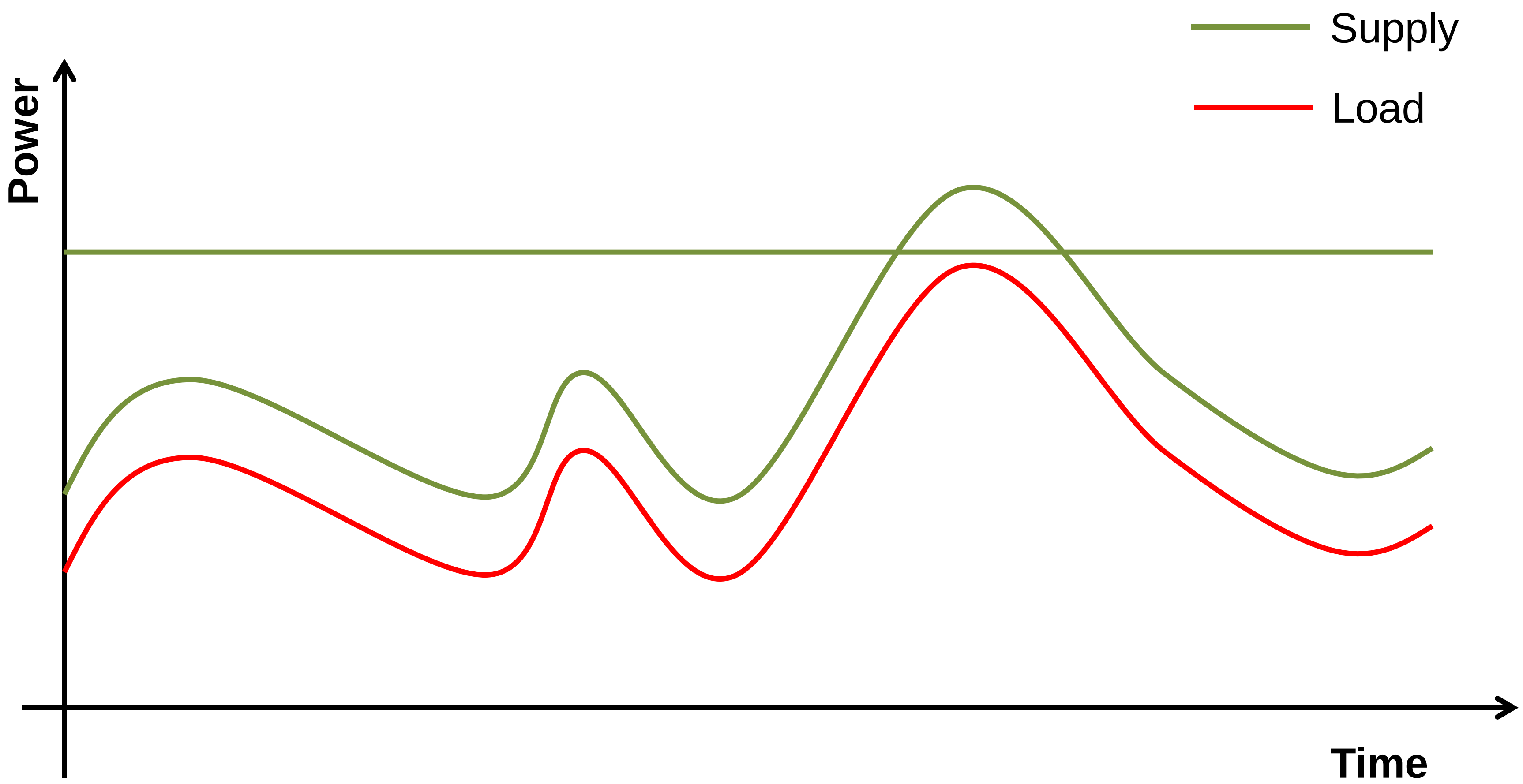
- In classical reliability theory:
  - MTBF, which only reports the mean of the time to failure distribution, is used.
  - Availability may be misleading if system can be repaired quickly.
- We propose a set of metrics useful in capturing different aspects of performance of a repairable system and then select a minimal set (e.g. cost, MFFP, number of failures).
- A small set of metrics can be used to represent system performance using a Pareto front so that the best design can be chosen.

# Microgrid and V2G Overview

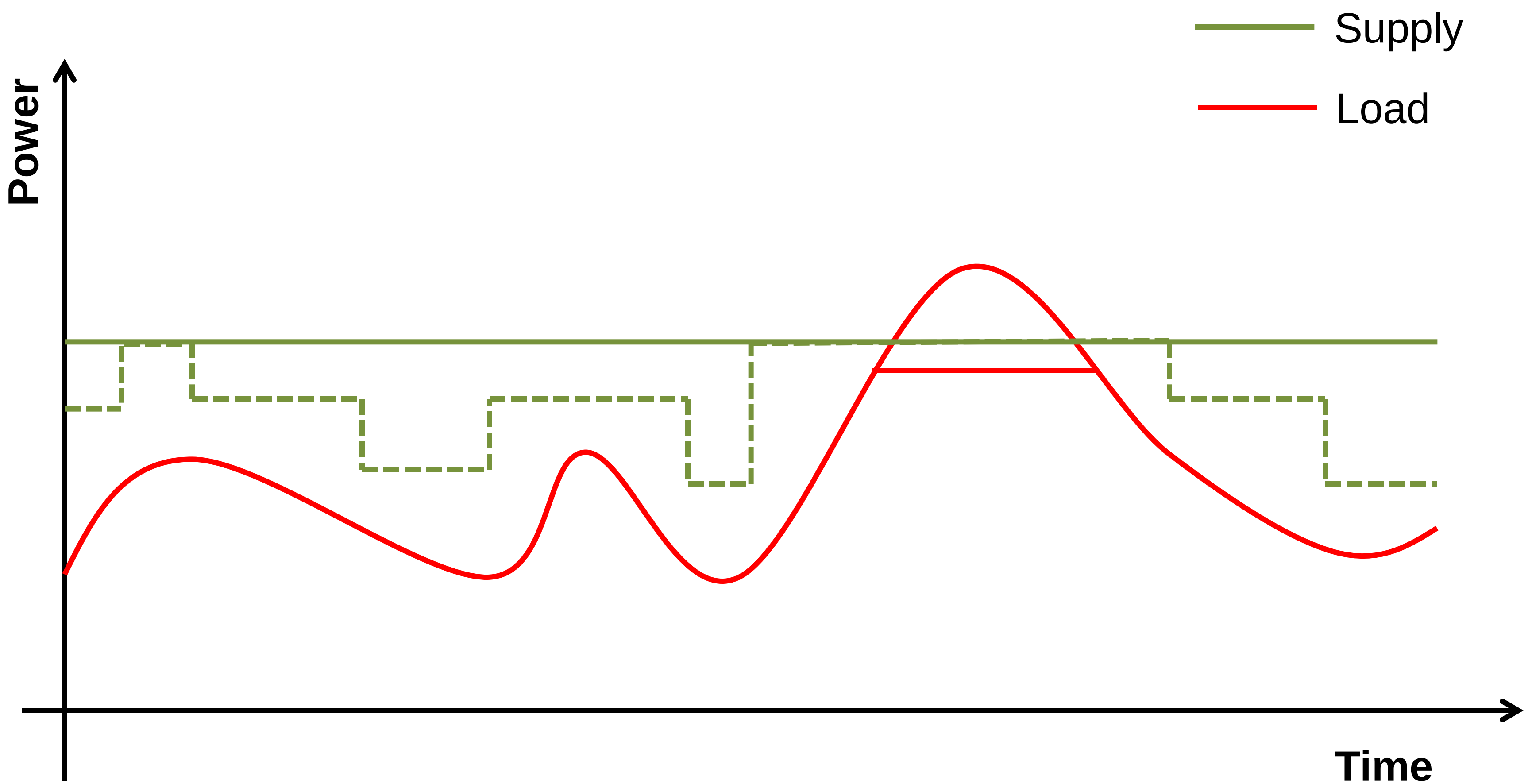
- Integrates power from multiple sources without loss of power quality
  - 2 x Solar PV (50 kW)
  - 2 x Diesel generators (200 kW)
  - Hybrid vehicles EV batteries (60 kWh @ max discharge rate of 10kW)
- Capable of peak-shaving and load-shedding if required
- Islanded
- Provides power to variable loads
  - Building loads
  - Other miscellaneous loads



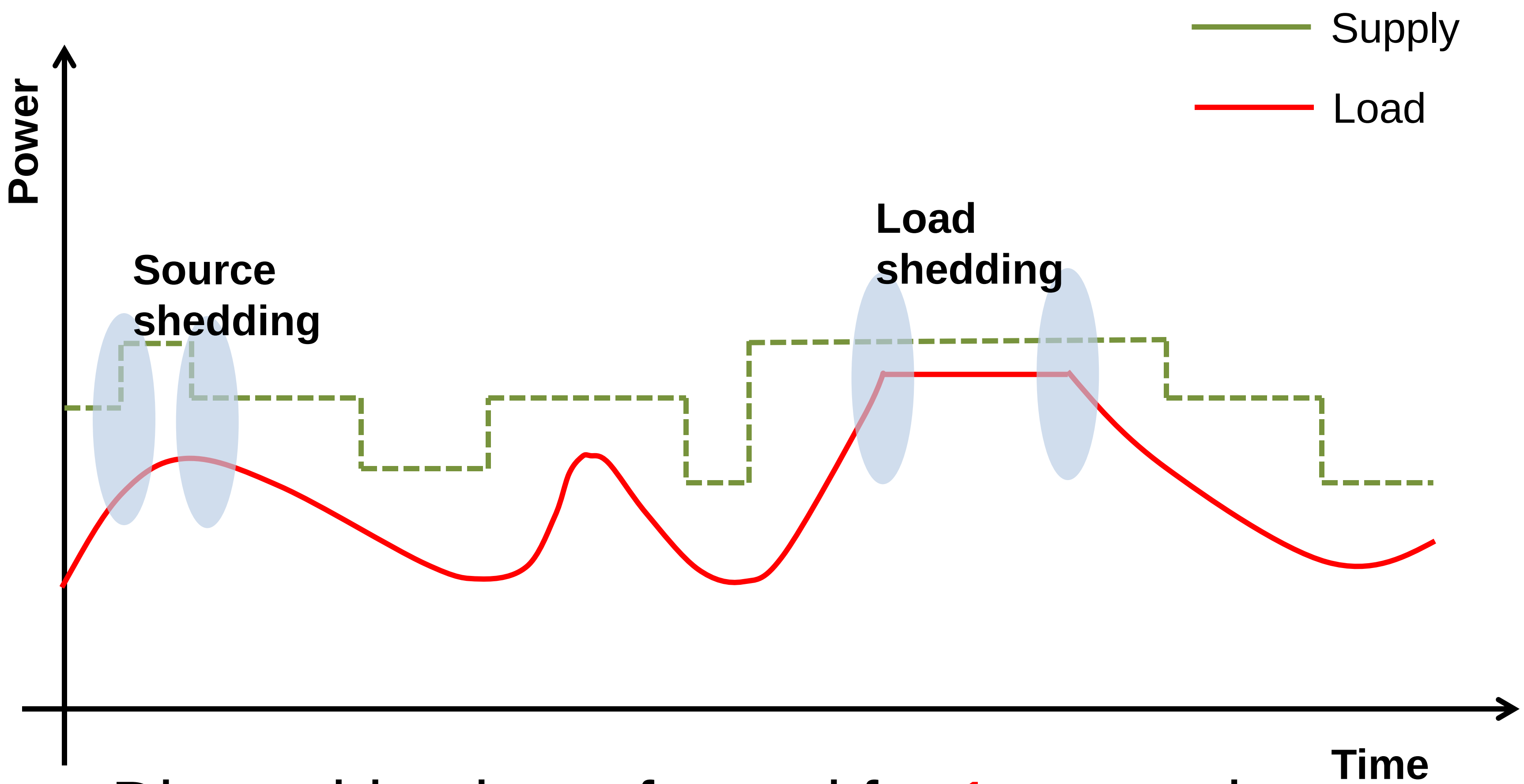
# Load and Source Dispatching



# Load and Source Dispatching

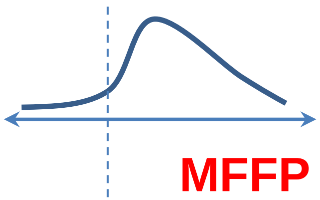


# Load and Source Dispatching




Dispatching is performed for 1 year using 1-hour increment

# Optimization Problem



$$\underset{\mathbf{x}}{Min}\{-T_{0.8}, N_f, C\}$$

MFFP with 80% probability

Number of failures

Cost

**NSGA-II Algorithm**

$$\text{where: } \mathbf{x} = \{s_{ls}, s_{so}, s_{lo}, s_{ss}, n_{gen}, n_{contacts}\}^T$$

$$T_{0.8} = F^{-1}_{T_{working}}(0.2)$$

$$C = C_{initial} + C_{repair} + C_{running}$$

Ruled-based set points (decision variables)

subject to:

$$g_1(\mathbf{x}): P = 8760,$$

Planning horizon

$$g_2(\mathbf{x}): p_{gen} = 0.25, \quad g_3(\mathbf{x}): \eta_{repair} = 0.1$$

$$n_{gen}, n_{contacts} \in N$$

$$s_{ls}, s_{so}, s_{lo}, s_{ss}, \in [0,100]$$

# Issues with Classical Approach

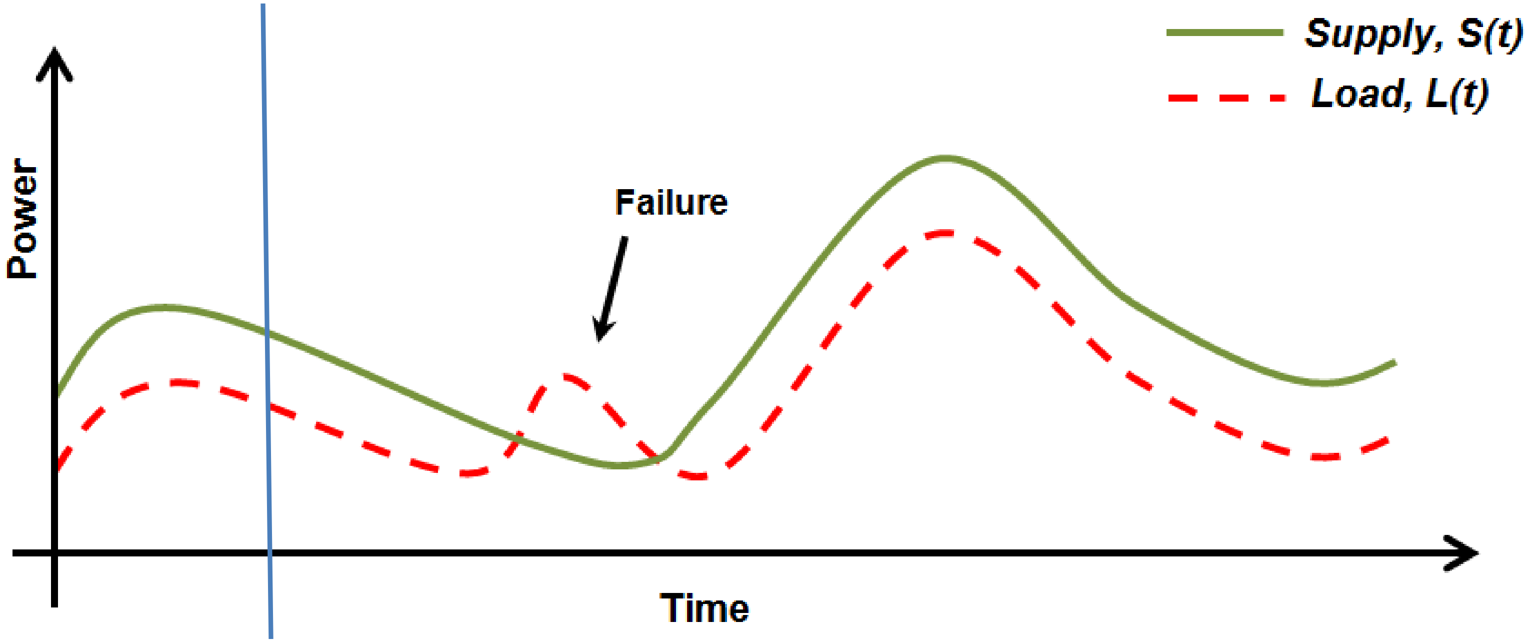
- **Incorrect extrapolations:** Unless done properly, what is learned in a short simulation time may not be applicable to the entire planning horizon.
- **Coarse time scales:** Many transient effects are not captured properly because they happen within seconds. The flip-side is that fine time scale simulations are computationally prohibitive.
- **Uncertainty:** The effect of uncertainty cannot be fully captured. For example, we may encounter a chance failure and assume that the microgrid is unreliable or alternatively by luck, we may not see any failure in a short period even if the microgrid is unreliable.

# Flexible Microgrid

- We are envisioning a flexible approach to microgrid design that "learns" from its behavior (loads and sources) and responds accordingly.
- Load follows a stochastic process and in response so does the supply.
- Failures are expected because of the stochasticity regardless of how well the loads are modeled.
- The dynamic microgrid system must be simulated with a very short time interval for months at a time in order to fully characterize its operation. This is computationally impractical.
- **Our methodology proposes to "learn" the characteristics of the load profile *L(t)* and the resulting supply profile *S(t)*, as enacted by an intelligent power management protocol.**

# Flexible Microgrid

- The correlation between *L(t)* and *S(t)* is also determined.
- A short period of a few days can be used to “learn” the process.
- The quantified stochastic behavior of *L(t)* and *S(t)* is used to extrapolate for the system performance metrics at later times.



# Current Research – Flexible Microgrid

- AR* time series models the load and source processes

$$L(t_i) = 150 + 100 sin\left(\frac{2\pi t}{24}\right) + 50(0.0345\varepsilon_{i-1} + 0.1552\varepsilon_{i-2} + 0.2069\varepsilon_{i-3} + 0.2586\varepsilon_{i-4} + 0.3448\varepsilon_i)$$

- Source can be modeled in two ways:

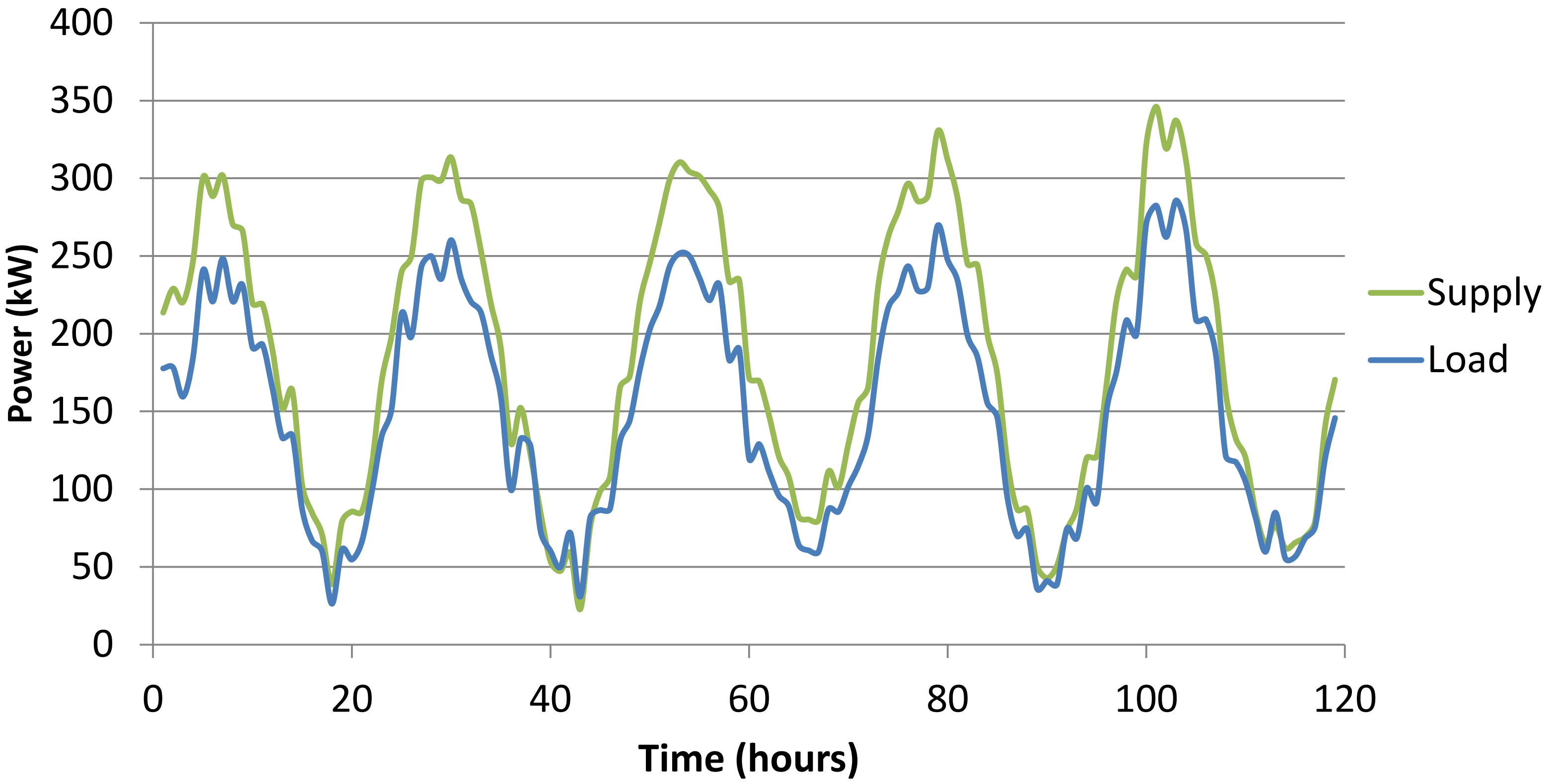
$$S(t_i) = (1+\phi)\left(150 + 100 sin\left(\frac{2\pi t}{24}\right)\right) + 50(0.0345\omega_{i-1} + 0.1552\omega_{i-2} + 0.2069\omega_{i-3} + 0.2586\omega_{i-4} + 0.3448\omega_i)$$

$$S(t_i) = \delta + 150 + 100 sin\left(\frac{2\pi t}{24}\right) + 50(0.0345\omega_{i-1} + 0.1552\omega_{i-2} + 0.2069\omega_{i-3} + 0.2586\omega_{i-4} + 0.3448\omega_i)$$

- The white noise terms $\omega_i$ and $\varepsilon_i$ are highly (but not perfectly) correlated because we never have a perfect model of the load.
- The first approach multiplies the load model by a factor while the second adds a fixed excess capacity.
- Our preliminary results show that the second approach is better.

***Auto-Regressive**

# Realization of Load and Sources



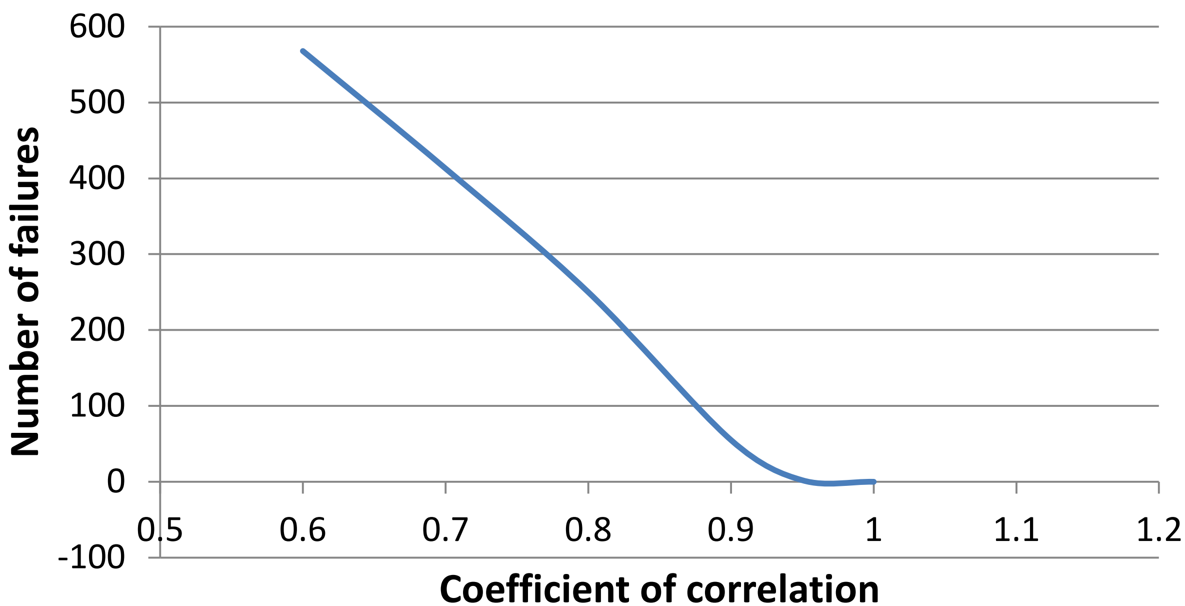
# Comparison of Strategies

- We assume that the electricity price is 10 cents per KWh.
- Realizations of the microgrid load and supply random processes are generated for 8760 hours.
- For comparison purposes, we fixed the number of failures.
- Strategy 1 generates 328,695.3 kWh of excess energy over the course of the year. This amounts to $32,869.53 in money spent for insurance against chance failures.
- Strategy 2 with an excess power of 20kW generates only 176,917.5 kWh of extra energy, which amounts to $17,691.75.

# Comparison of Strategies

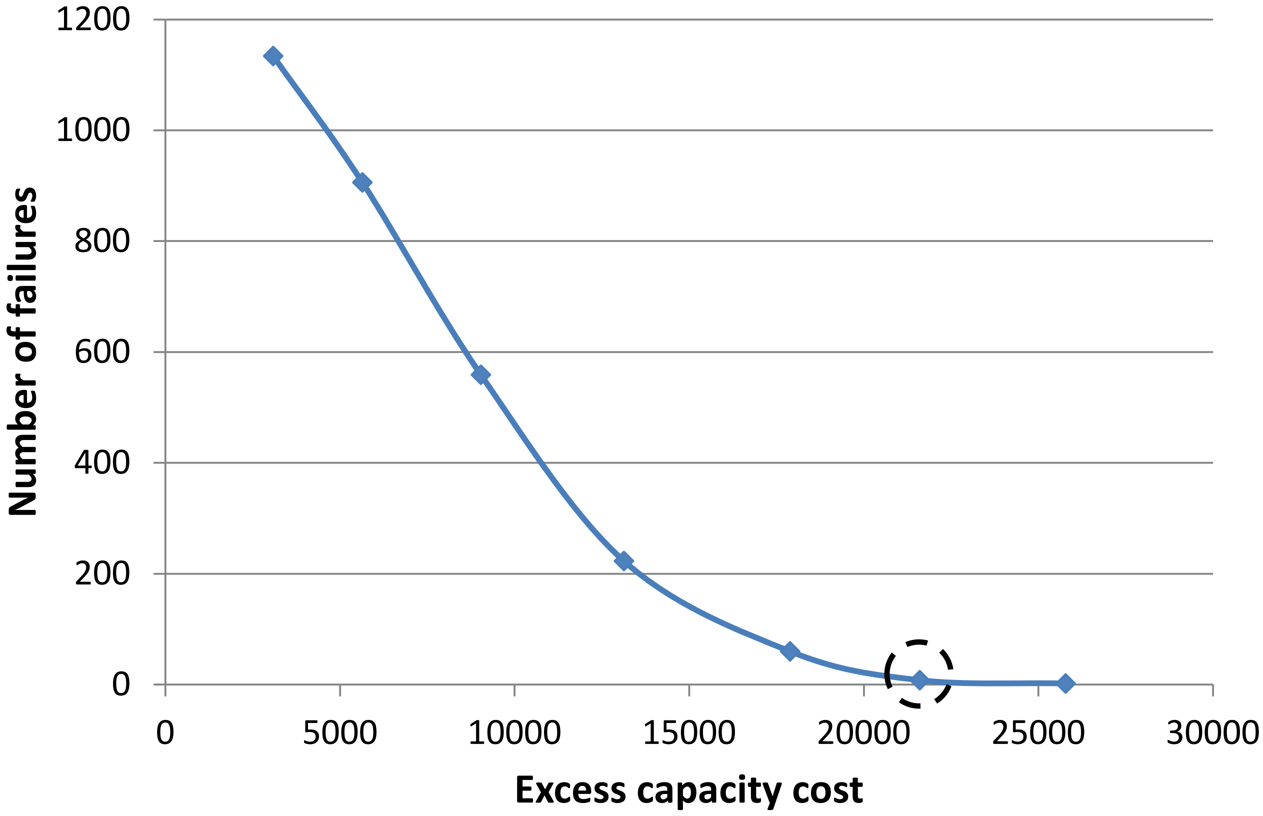
- As a result, we use Strategy 2 for further analysis.
- Building extra supply capacity as a percentage of load is wasteful because when the load is high, there is less likelihood of it increasing substantially anymore while the opposite is true when the load is low.
- Strategy 2 also gives provides an easier way to predict cost.
- We also propose that one should only look at the cost incurred in providing excess power as the microgrid running cost.

# Sensitivity To The Correlation Between Load and Source




- The failures fall to zero when the supply is perfectly correlated with the load.
  - Good modeling of the load and responding with a supply that will meet that load quickly are essential.
  - Cost does not decrease much if correlation increases.

# Pareto Front over Cost and Number of Failures



# Design Details

- If the decision maker selects the design shown:
  - Strategy 2 to provide excess supply
  - Cost = $21,602 in excess power
  - Number of failures = 8
  - $\delta$ = 25 kW
  - MFFP = 97.4 hours
  - Correlation $\rho$ = 0.9.

# Conclusions

- An optimal microgrid architecture can be obtained, considering performance, reliability and lifecycle cost.
- The overall system must be treated as a repairable system
- This work proposes a flexible approach to microgrid design that "learns" from its behavior (loads and sources) and responds accordingly. This approach allows for significant reduction in computational effort.
- Our results showed the proper modeling of load is critical, so is responding with a highly correlated supply.
- Two strategies were compared, our results showed that to account for variability in load, one should respond with a supply that is fixed kW above the expected load.
- Other scenarios were also investigated such as: effect of correlation between load and source, as well as tradeoff between the attributes of cost and number of failures (Pareto front).

Thanks for your attention

**Q & A**